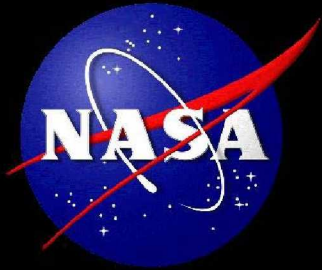


Activation of Lunar Dust via Grinding and UV Irradiation



W.T. Wallace
Wyle/NASA Johnson Space Center
Houston, TX

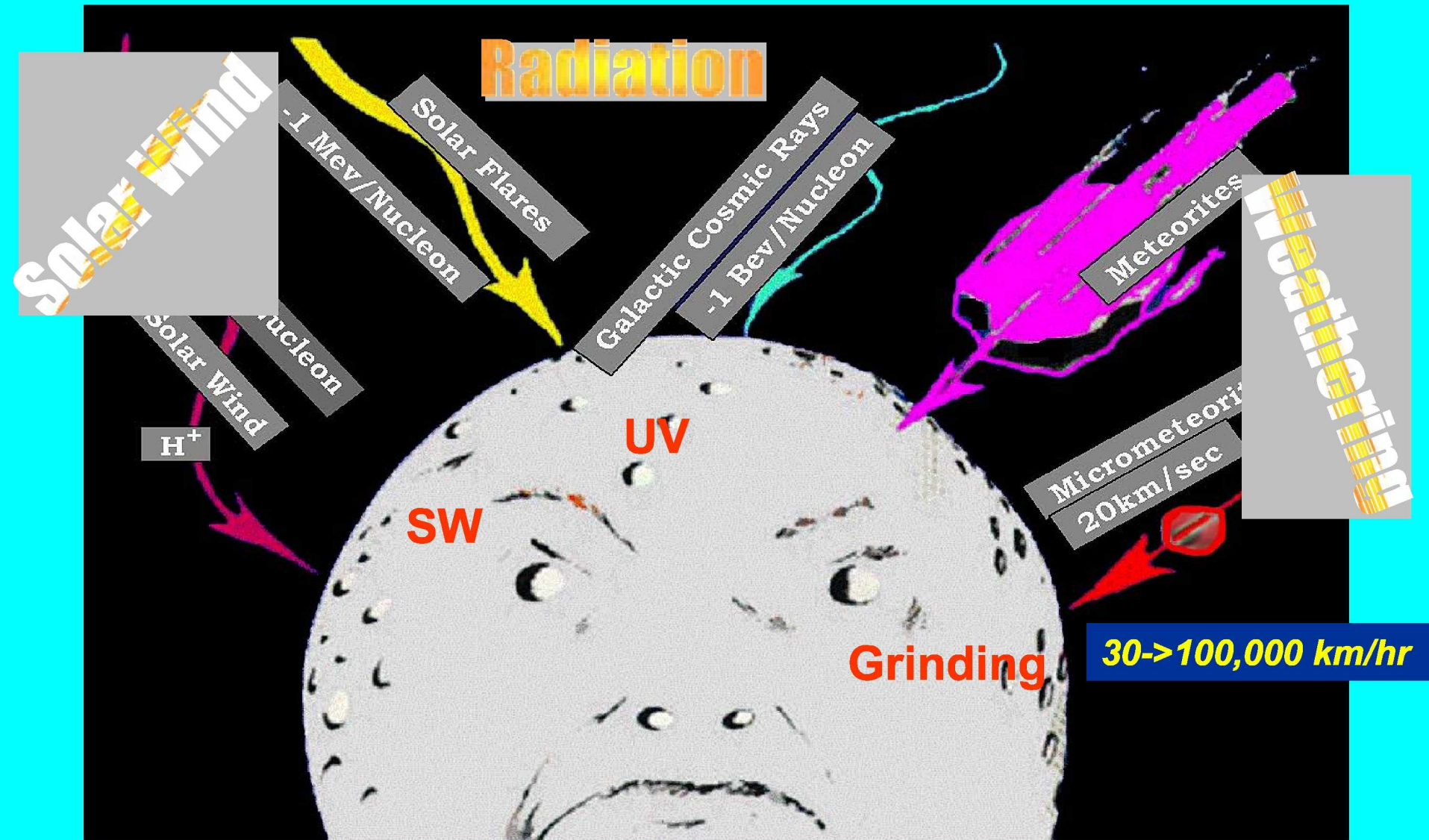
A.S. Jeevarajan
NASA Johnson Space Center
Houston, TX

L.A. Taylor
University of Tennessee-Knoxville

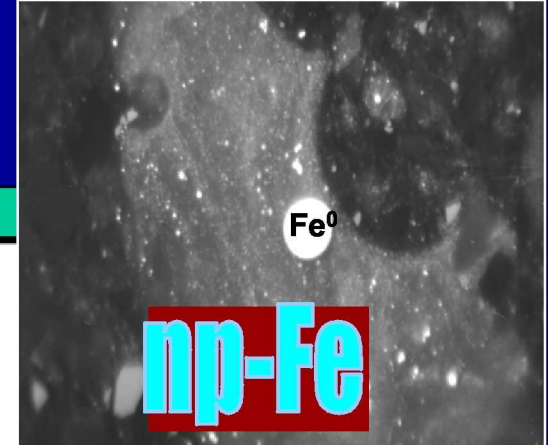
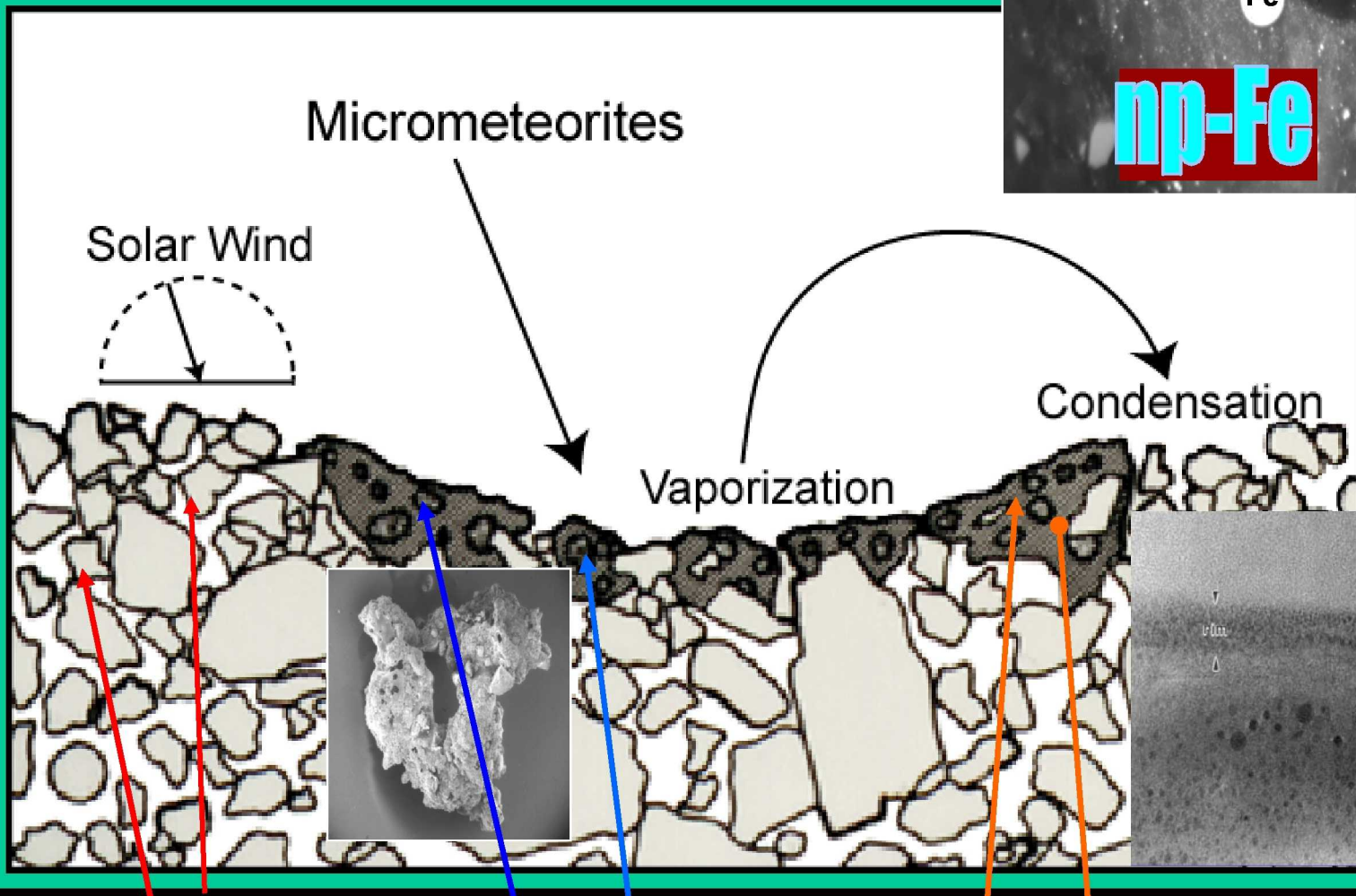
Lunar Dust Reactivity

- ◆ Activation of Dust: micro-meteorite impacts; UV radiation; solar-wind particle impacts
- ◆ No passivating atmosphere; 10^{-12} torr
- ◆ Active Dust: create reactive species in lungs or humid environment
- ◆ Monitor production of reactive species
- ◆ Determine methods of deactivation
- ◆ Need method to *reactivate* lunar dust on Earth
 - ◆ Lack of pristine reactive lunar soil
- ◆ Major causes of reactivity

Our Unhappy Moon

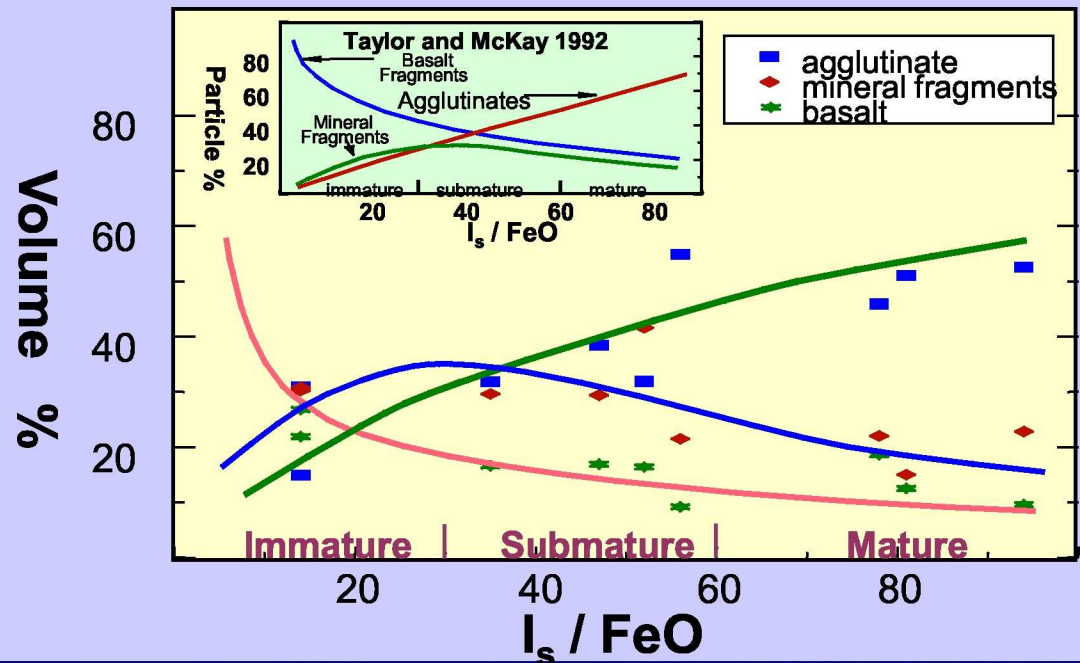


Lunar Soil Formation



Comminution, Agglutination, & Vapor Deposition

Soil Maturity

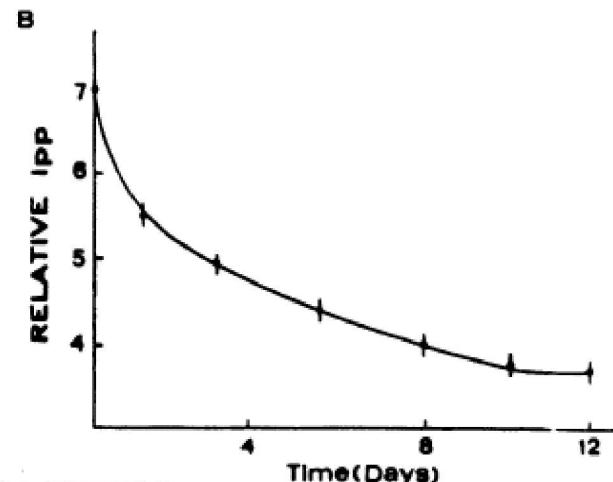


- Measurement of Single-Domain, Nanophase Fe^0 (I_s) FMR
- Normalized I_s for Iron Content: I_s / FeO
- **I_s / FeO = amount of total iron present as Fe^0**
- I_s / FeO is a Function of Agglutinate Abundance
- Agglutinate Abundance is a Function of Maturity

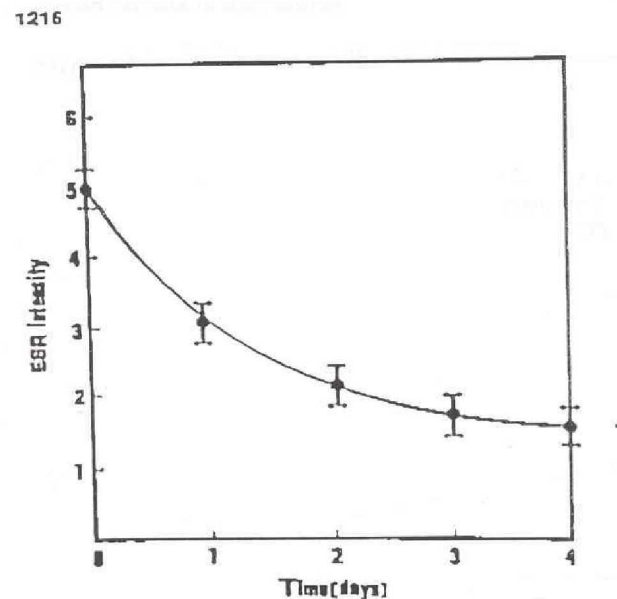
$$I_s / \text{FeO} = \text{Soil Maturity}$$

Quartz Activation by Grinding

- Grinding quartz: electron spin resonance (ESR) characteristic of $\text{Si}\cdot$ or $\text{Si-O}\cdot$ radicals
- Increased grinding = higher signal
- Decrease in Si-based radicals in air
- Half-life ~30 hours; at 4 weeks = still 20% signal



- Ground quartz + H_2O = $\text{OH}\cdot$ in aqueous solution produces OH radicals
- Air = Decrease in Radical production
- Half life ~ 20 hours

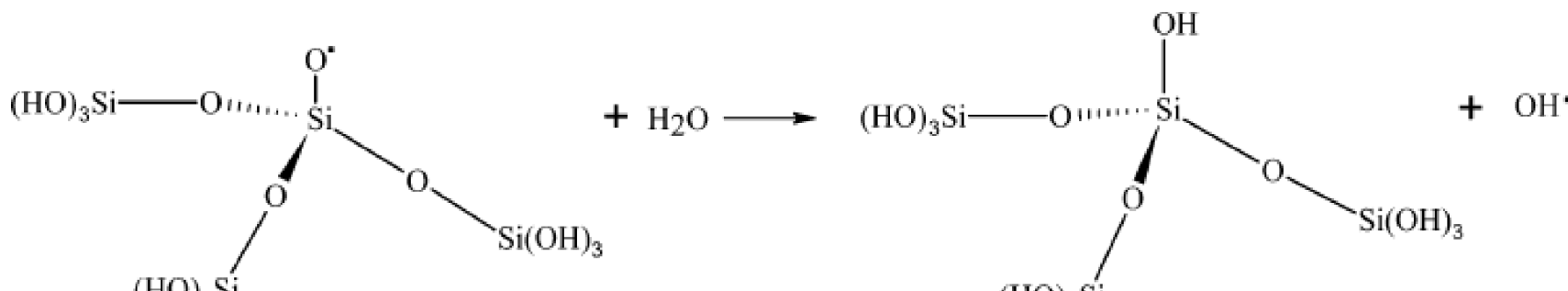


V. Castranova, *Environ. Health Perspect.* 102 (1994) 65-68.

V. Vallyathan et al., *Am. Rev. Respir. Dis.* 138 (1998) 1213-1219

What Does “Activated” Mean?

- Presence of reactive sites on surface - Free radicals
- Ability to produce reactive species in solution



J. Narayanasamy and J.D. Kubicki, *J. Phys. Chem. B* 109 (2005) 21796-21807

Reactive Species of Interest

- Hydroxyl Radical, $\cdot\text{OH}$
- Highly oxidizing
- Damage & Radical species production

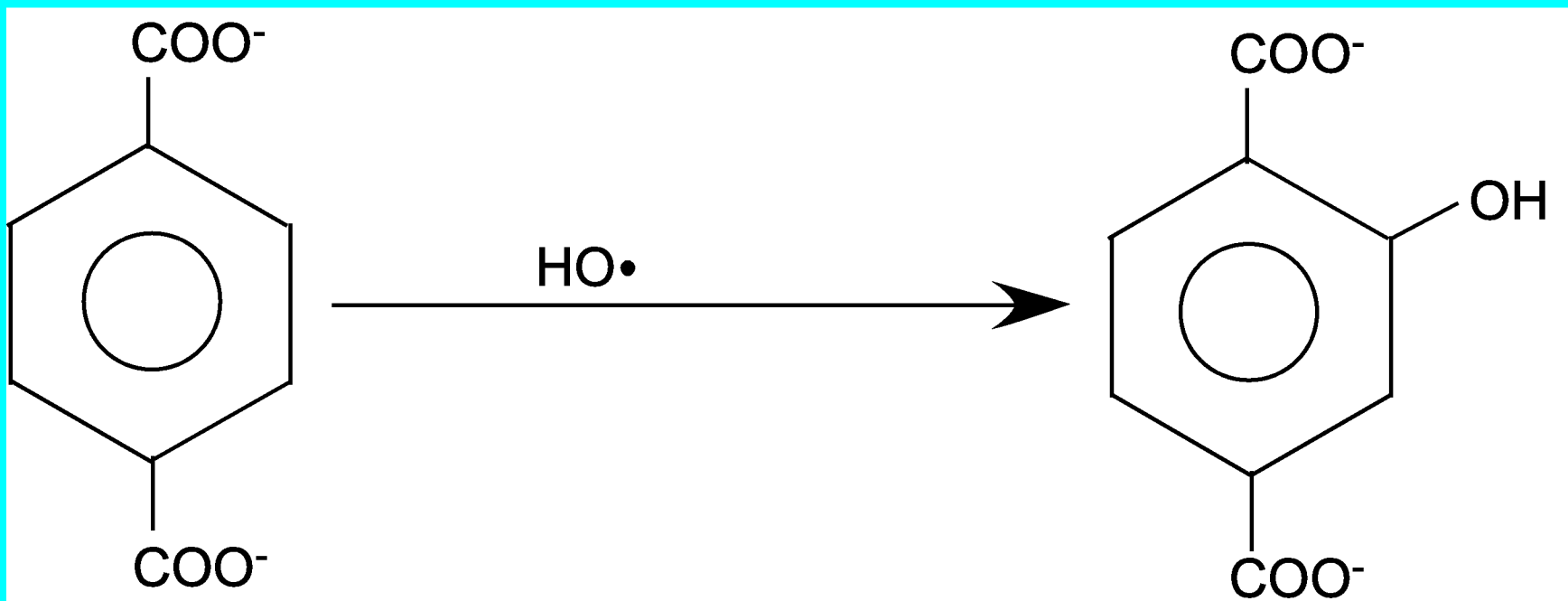
How Should We Monitor $\cdot\text{OH}$?

- Fluorescence Spectroscopy
 - Can also provide quantitative analysis
 - Large number of chemical sensors already in use for other systems
 - Need to determine correct probe
- Electron Spin Resonance
 - Provides quantitative measure of radical production
 - Equipment is costly and bulky



Fluorescence

Monitoring Hydroxyl Radical Production



Terephthalate
(**non-fluorescent**)

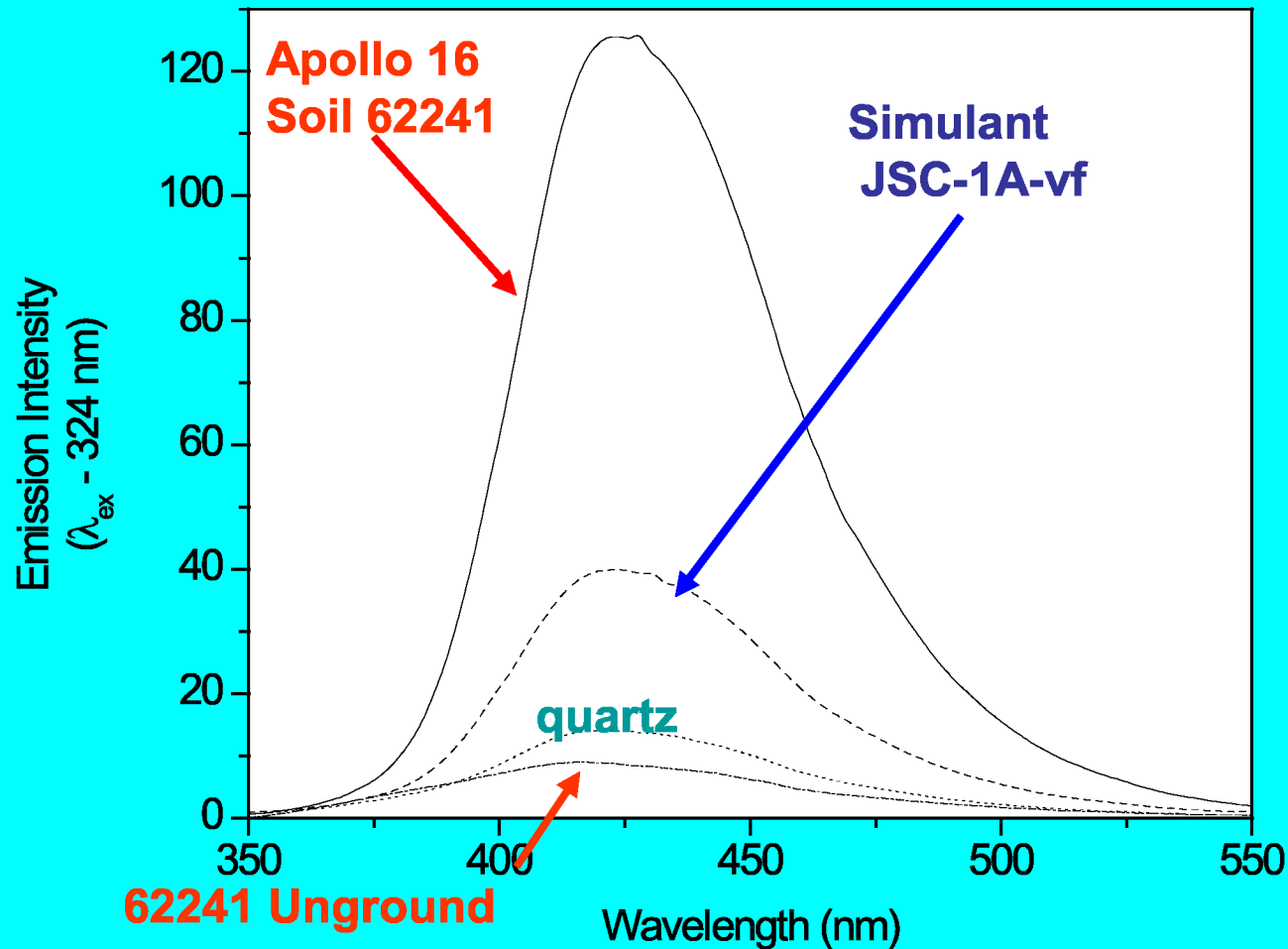
2-Hydroxyterephthalate
(**fluorescent**)

Grinding Experiments

Bulk Chemistry and Maturity

Sample	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
JSC-1A-vf, % oxides	48.8	15.7	1.49	8.88 + 1.71% Fe ₂ O ₃	0.19	8.48	10.4	2.93	0.81	0.66
Apollo 16 Soil (62241), % oxides I _s /FeO = 100	44.7	27	0.56	5.49	0.7	5.84	15.9	0.44	0.13	0.1
Min-U-Sil Quartz, % oxides	99 +	< 0.8	< 0.1	< 0.1 Fe ₂ O ₃	0	0	0	0	0	0

Grinding Experiments



**Apollo 16
Soil 62241**

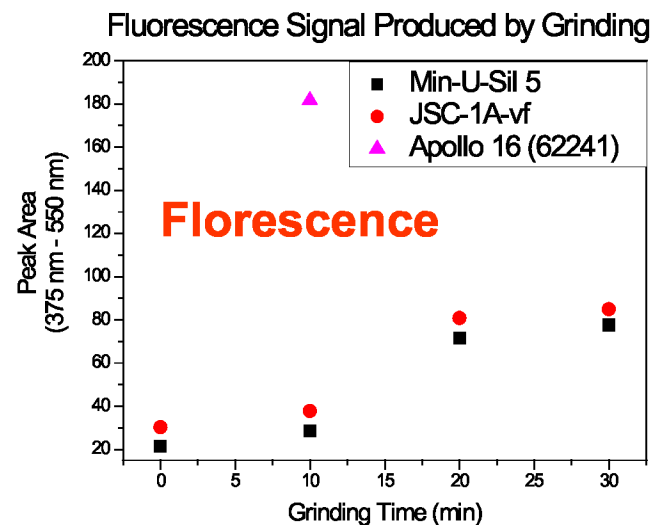
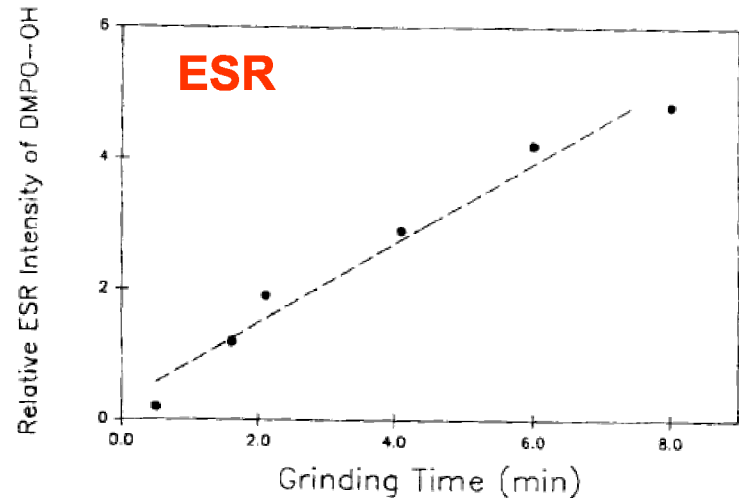
**Simulant
JSC-1A-vf**

quartz

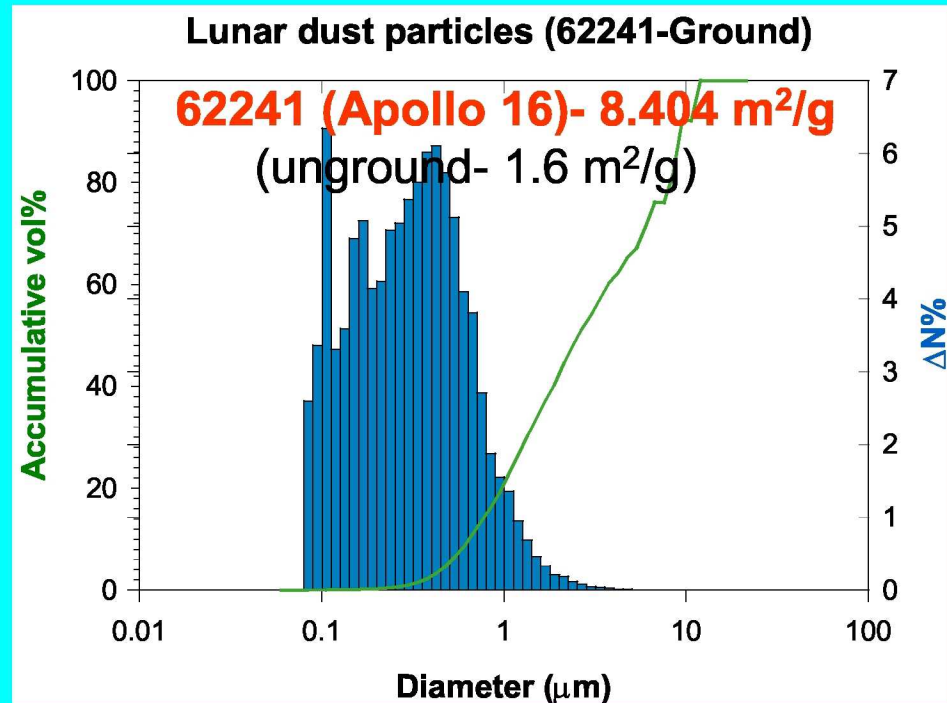
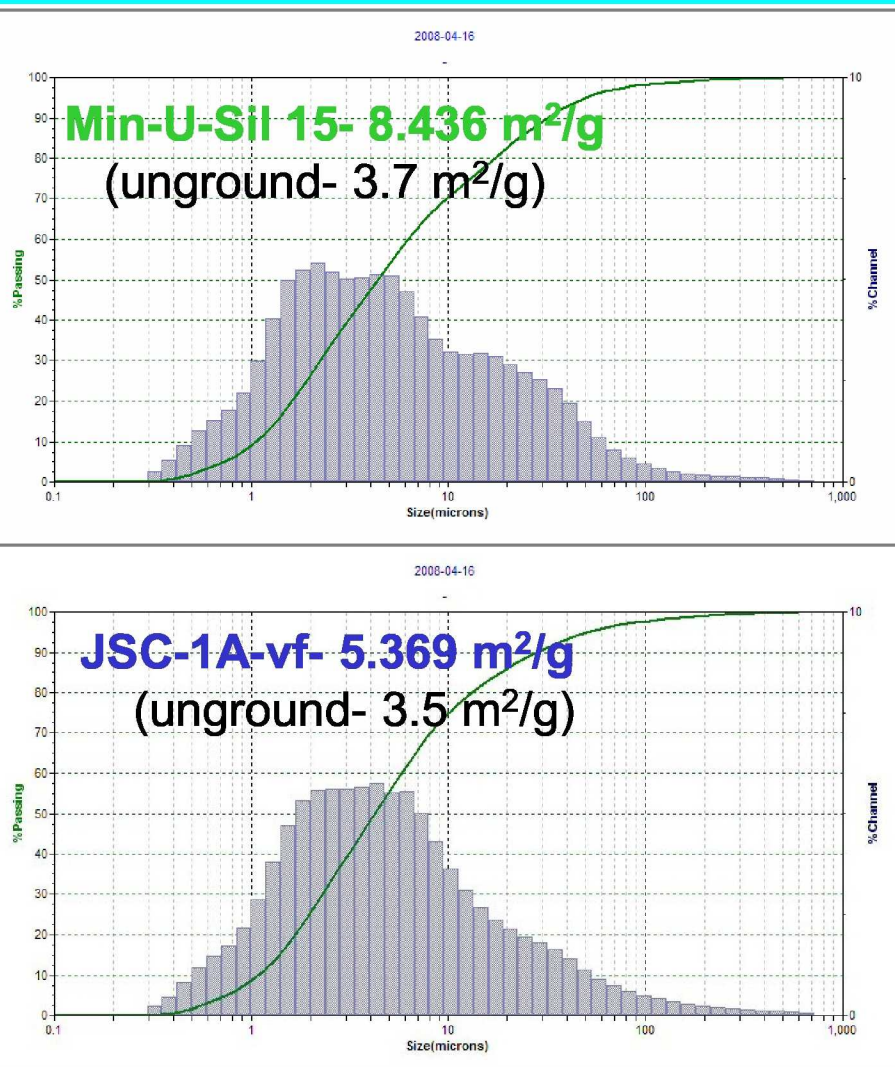
Wallace et al., (2009) Meteor. Planet. Sci. 44, 961-970

Effect of Grinding Time

- ◆ Grinding: produces higher number of silicon-based radicals in ESR spectra
- ◆ Grinding time: direct effect on hydroxyl radicals produced
- ◆ Grinding: increase in hydroxyl production for lunar simulant and quartz with increased grinding
- ◆ **Grinding: Apollo Soil greatly increases $\cdot\text{OH}$**



Size Distribution AFTER Grinding



Soil Chemistry and Maturity

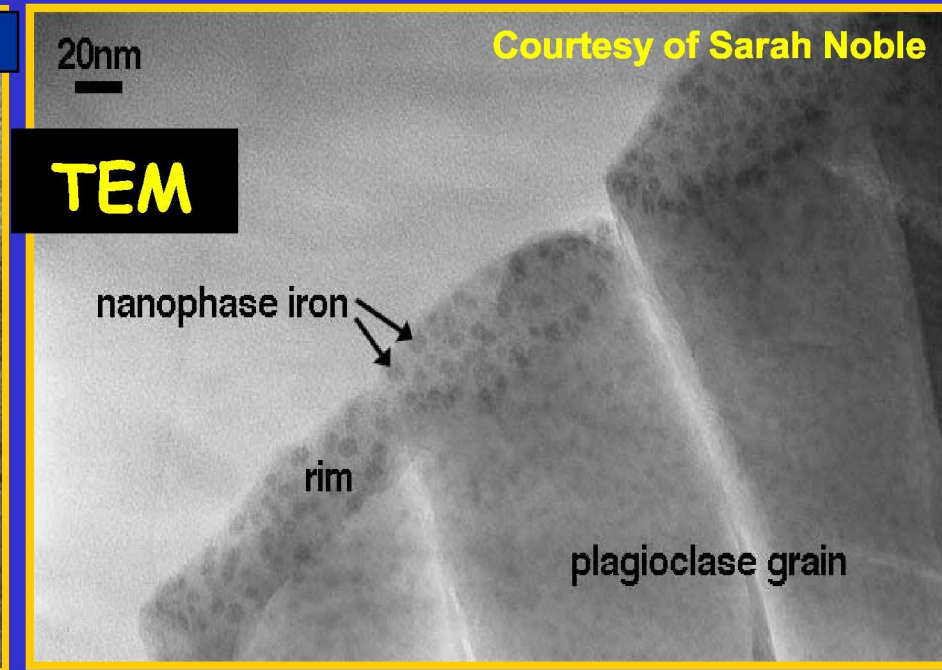
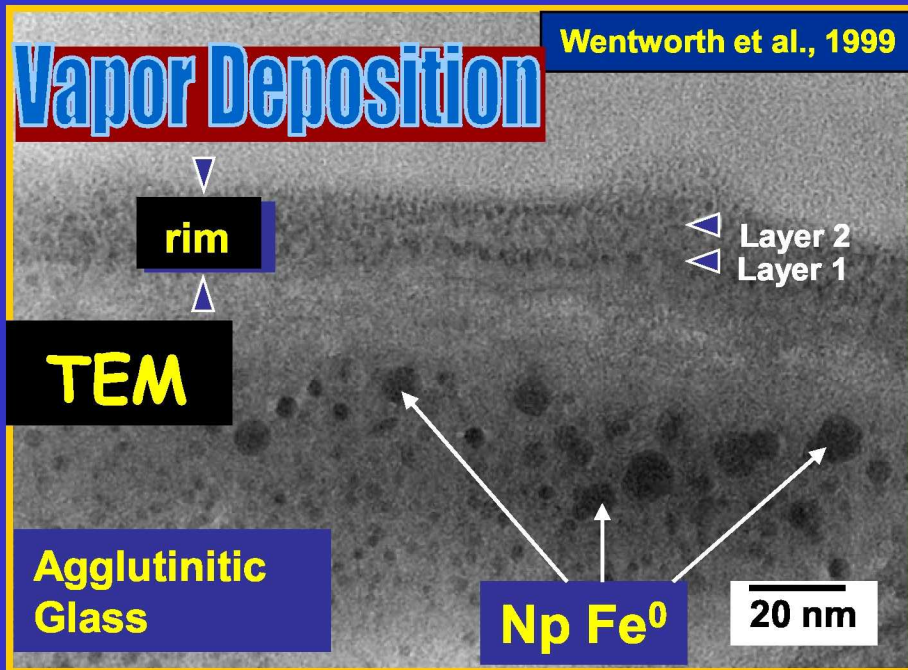
Lo-Ti Mare

Hi-Ti Mare

Highlands

Sample	15071	15041	71061	79221	67461	67481	61141	62231	62241
I _s /FeO	52	94	14	81	25	31	56	91	100
SiO ₂	45.9	46.4	39.8	41.7	44.6	44.6	45.0	45.0	44.65
TiO ₂	1.81	1.83	8.76	6.39	0.35	0.44	0.59	0.60	0.56
Al ₂ O ₃	13.1	13.5	10.5	13.5	28.4	28.1	26.3	26.3	27
Cr ₂ O ₃	0.41	0.41	0.48	0.37	0.08	0.10	0.12	0.11	-
MgO	11.3	10.8	10.5	10.3	4.46	4.91	6.39	6.20	5.84
CaO	10.3	10.3	9.90	10.8	16.5	16.2	15.3	15.4	15.95
MnO	0.19	0.20	0.24	0.21	0.06	0.06	0.07	0.09	0.7
FeO	14.9	14.2	17.5	14.0	4.24	4.38	4.80	4.87	5.49
Na ₂ O	0.37	0.41	0.41	0.41	0.40	0.43	0.43	0.43	0.44
K ₂ O	0.13	0.19	0.09	0.09	0.06	0.06	0.11	0.12	0.13
P ₂ O ₅	0.18	0.21	0.06	0.07	0.04	0.04	0.06	0.07	0.1
SO ₂	0.12	0.13	0.15	0.19	0.06	0.04	0.09	0.09	-

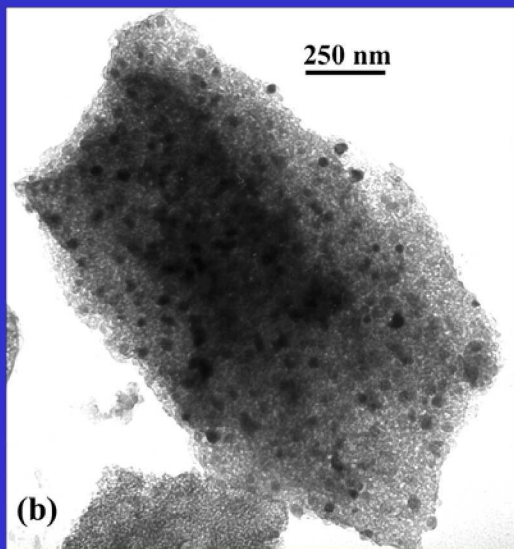
Metallic Fe TOXICITY on Dissolution of Glass ?



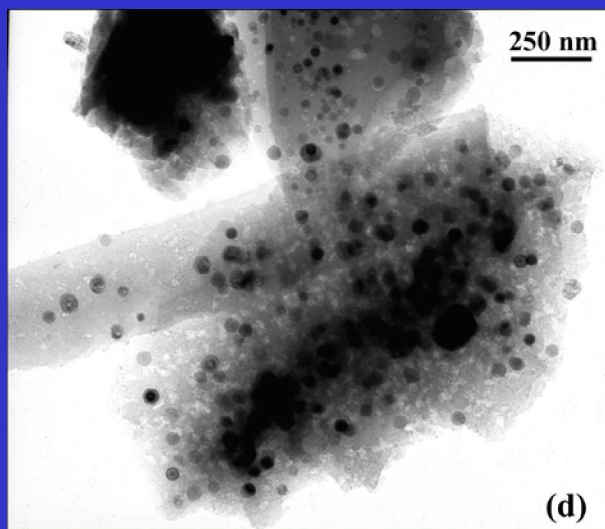
Glassy rims produced by vapor/sputter deposition
Single-Domain Fe = 3-33 nm nanophase Fe

Synthesis of NP-Fe in SiO_2 Glass

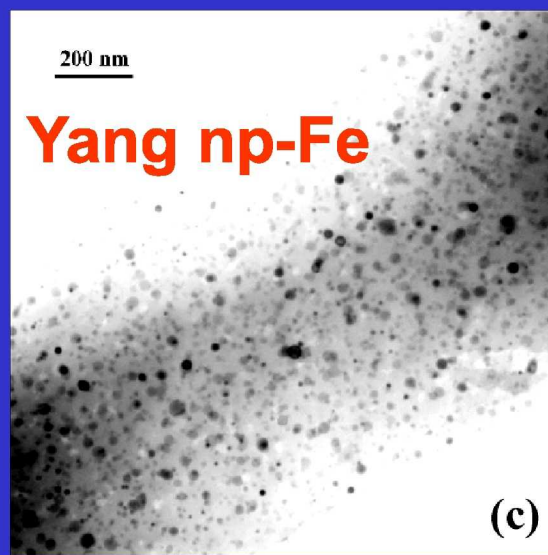
TEM Photos



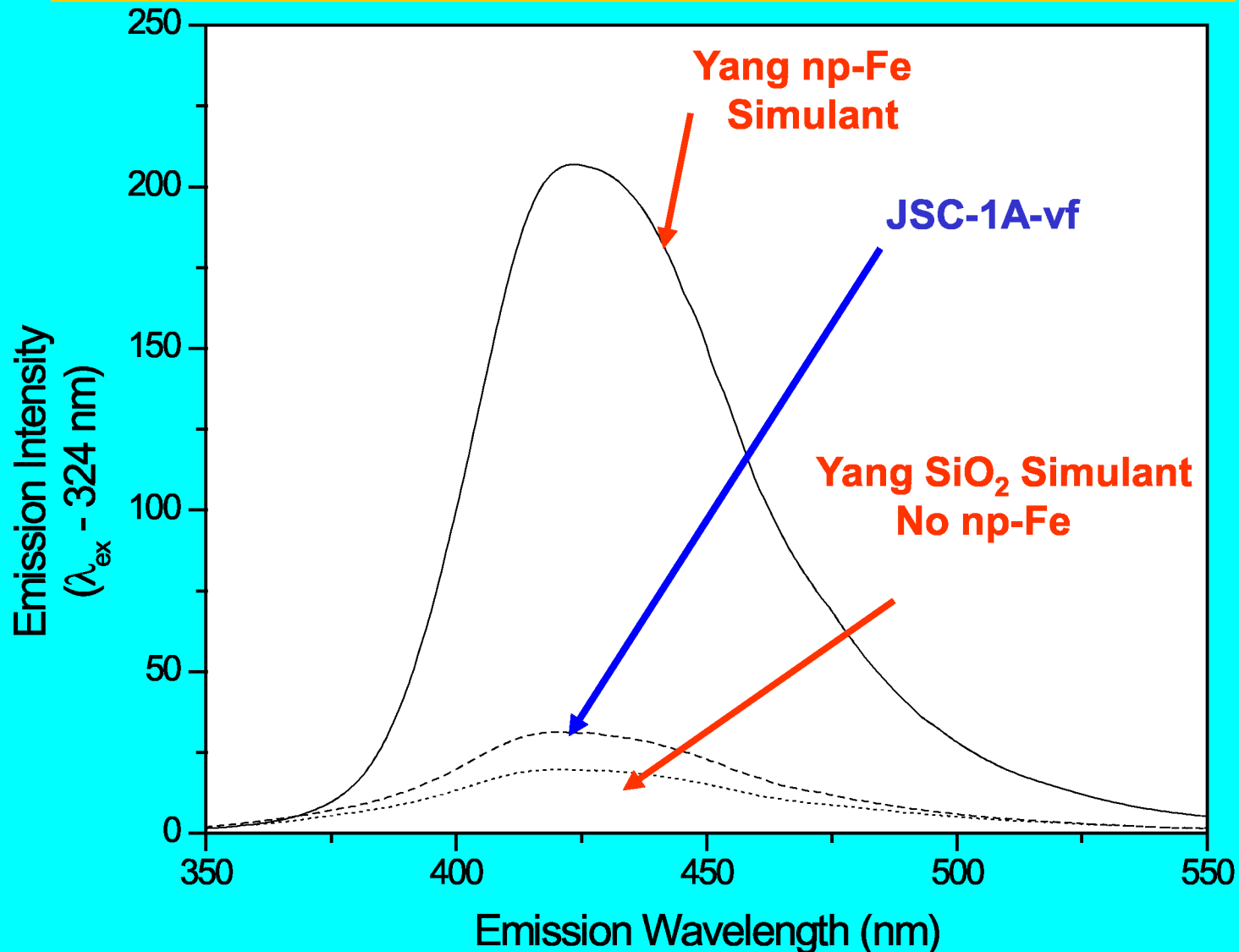
All Black Dots are
Nanophase Fe



Liu et al., 2007

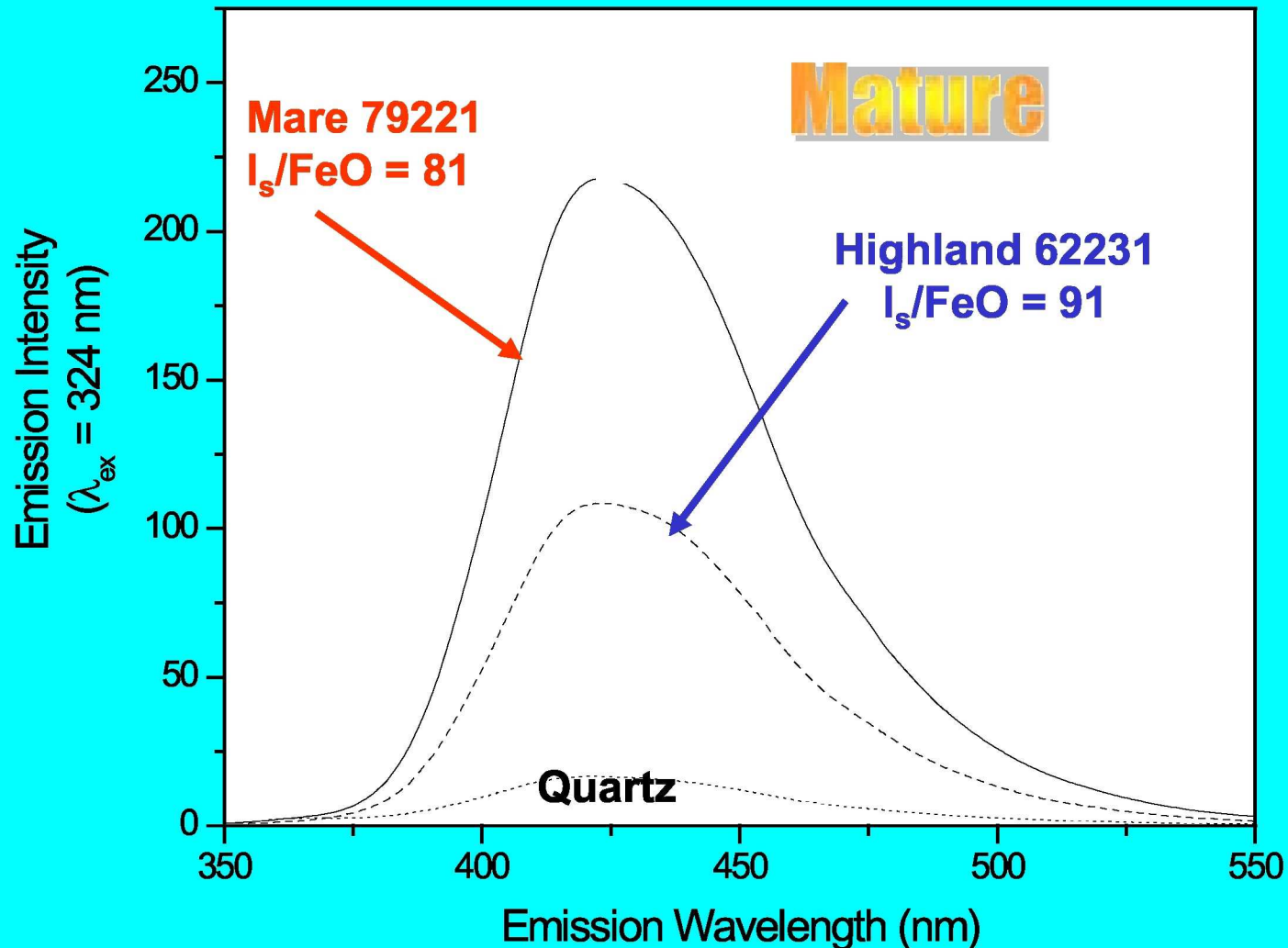


Effects of Nanophase Iron



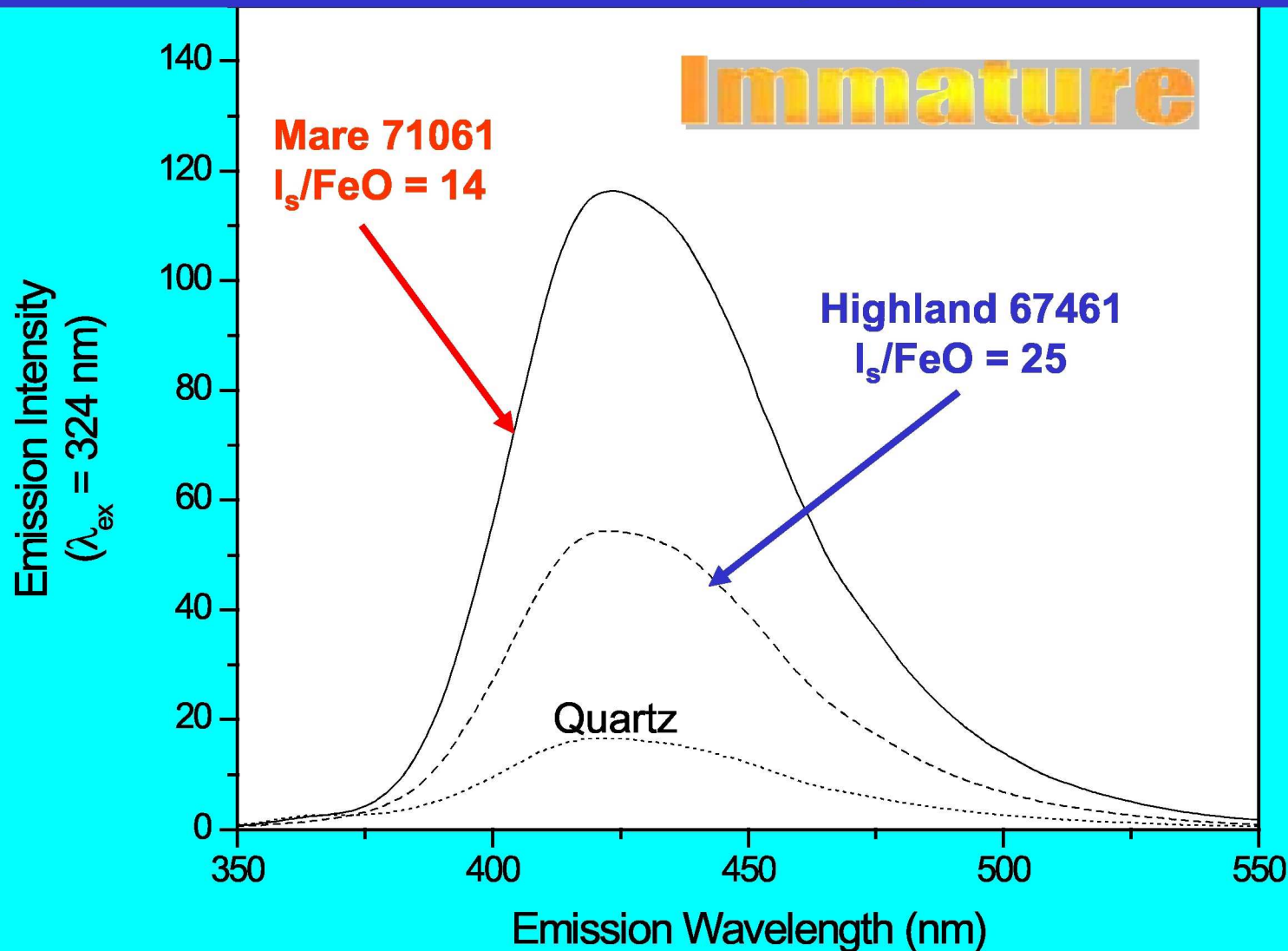
Wallace et al., *Earth Planet. Sci. Lett.* (2009) submitted.

Effects of Dust Source (Highland vs Mare)



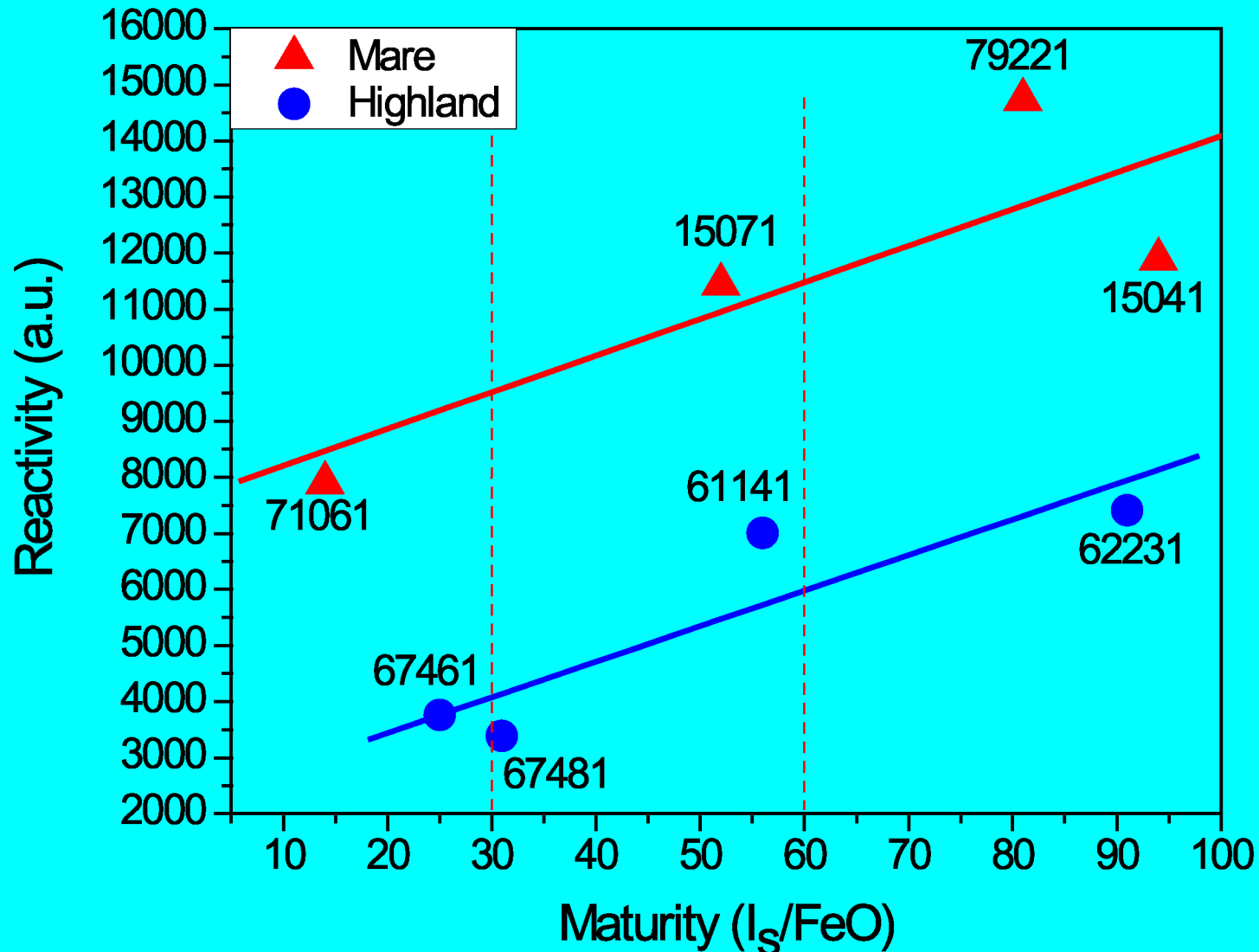
Wallace et al., *Earth Planet. Sci. Lett.* (2009) submitted.

Effects of Dust Source (Highland vs Mare)



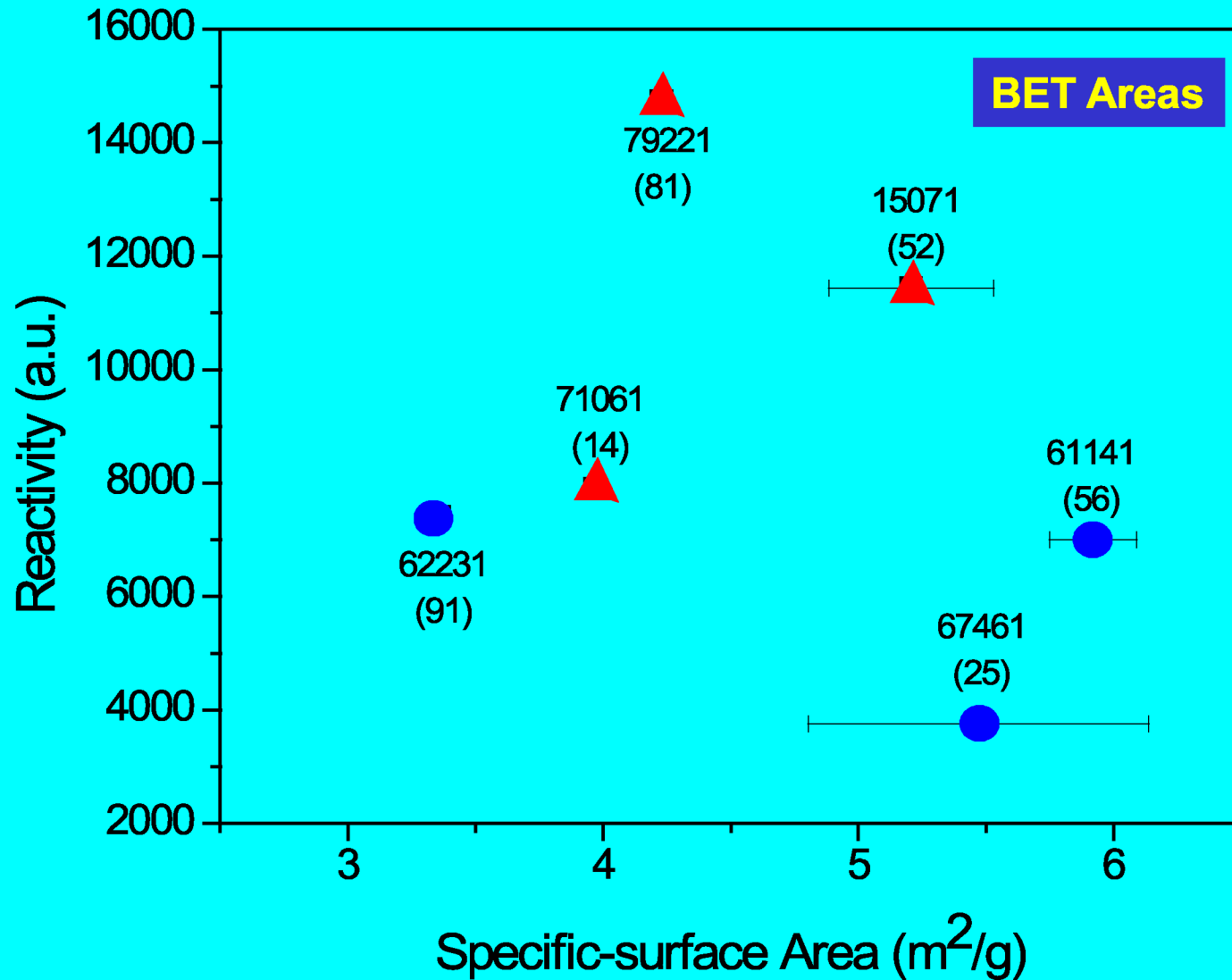
Wallace et al., *Earth Planet. Sci. Lett.* (2009) submitted.

Effects of Maturity on Reactivity



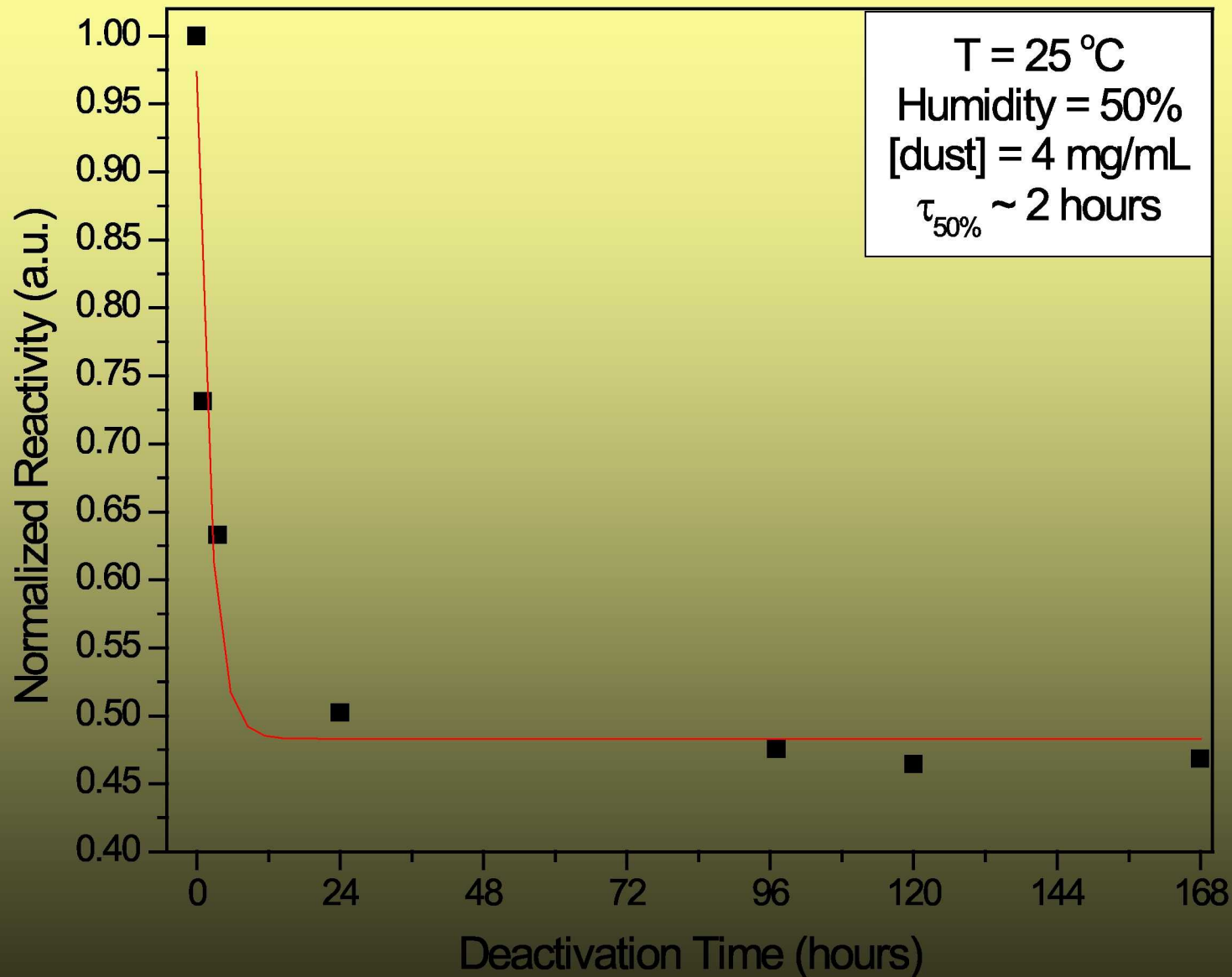
Wallace et al., *Earth Planet. Sci. Lett.* (2009) submitted.

REACTIVITY: Effects of Surface Area

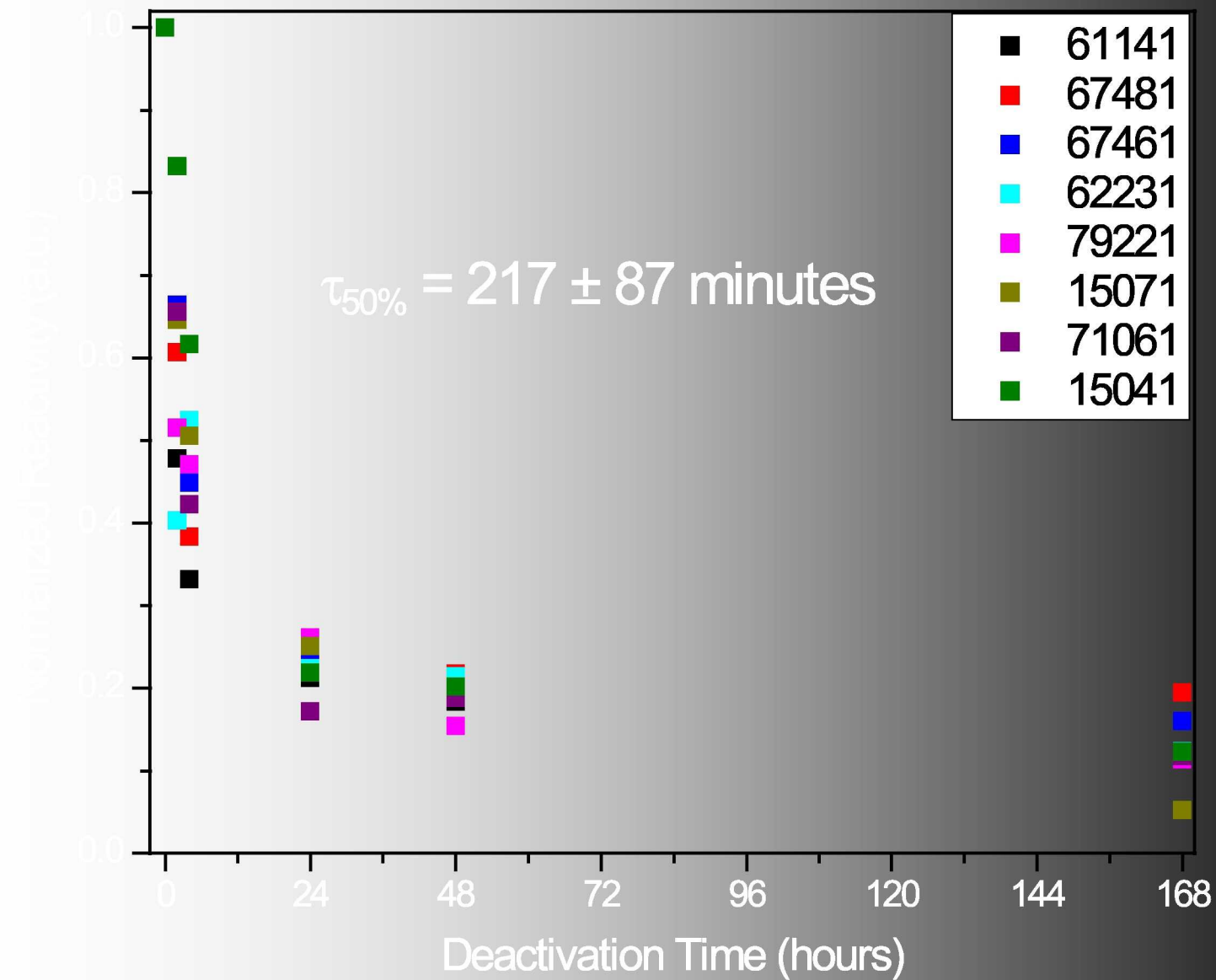


Wallace et al., *Earth Planet. Sci. Lett.* (2009) submitted.

Deactivation of JSC-1A-vf



Deactivation of Lunar Soils



TAKE - HOMES



**Lunar Soil is Highly Activated by Grinding;
Dependent upon Soil Maturity and Locale.**



**RECALL: I_s/FeO is Measure of the Amount of NP-Fe
in a Soil Relative to the Total Iron as FeO.**



**LUNAR SOIL ACTIVITY IS A DIRECT FUNCTION
OF AMOUNT OF NP-Fe PRESENT.**



**Fluorescence and EPR can Measure Soil Activity;
Fluorescence can be Quantified.**

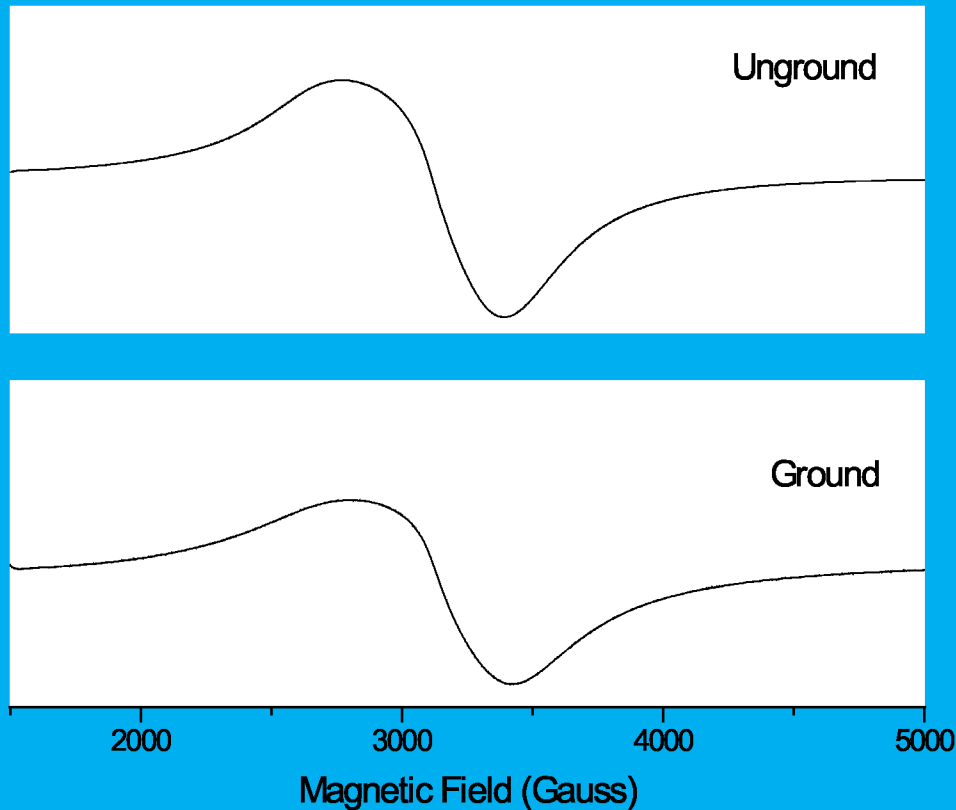


**CAUTION: Keller has Stated that in Mature Soils
Most Soil Particles are Glass + NP-Fe Coated;
Passifier of Grinding-Produced Dangling Bonds??**



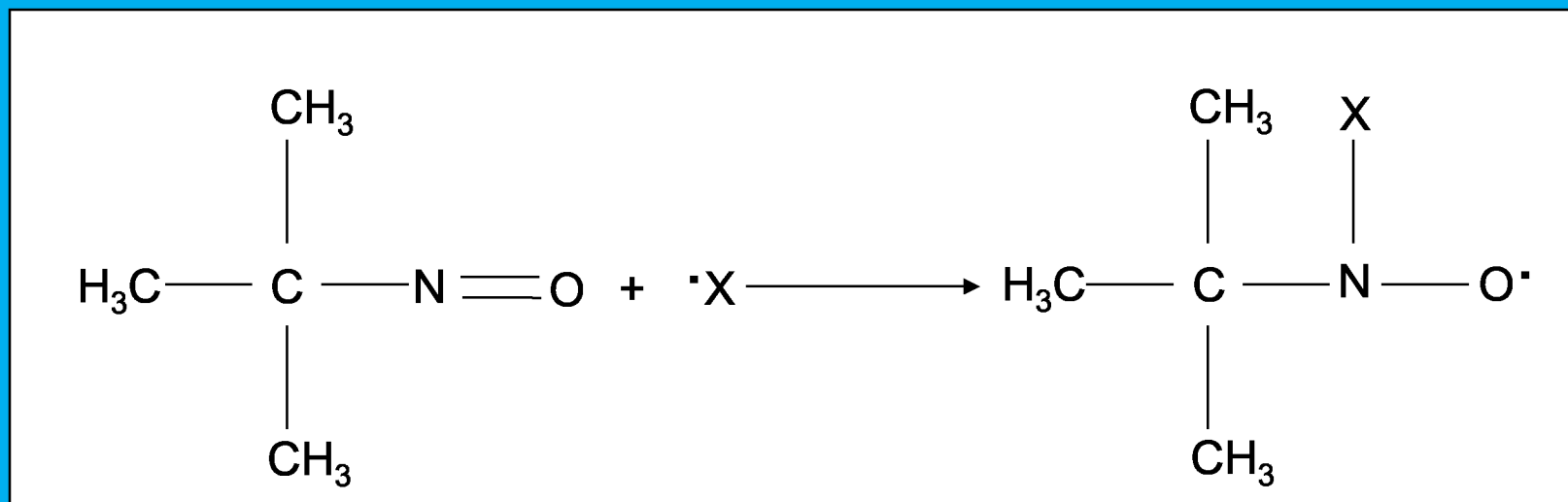
EPR

EPR Spectra of Apollo 62241



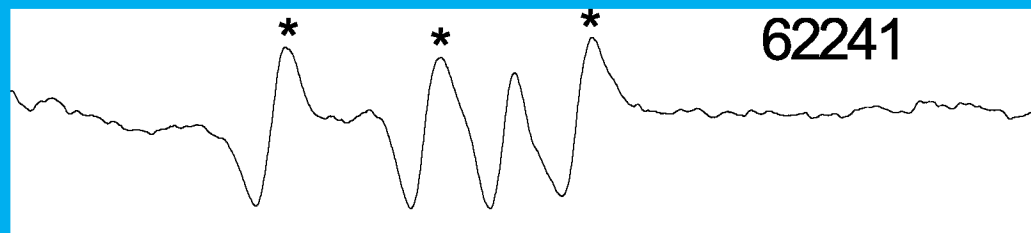
- Same grinding conditions as fluorescence studies
- Broad peaks
 - Si^\bullet or Si-O^\bullet ?
- g-values: $2.11 \longrightarrow 2.09$ (unground \longrightarrow ground)
- Similar to previous results*

Testing for Radicals Using Spin Traps

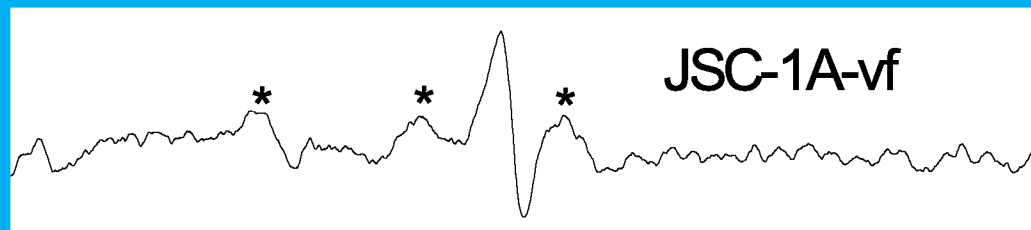


2-methyl-2-nitropropane (MNP)

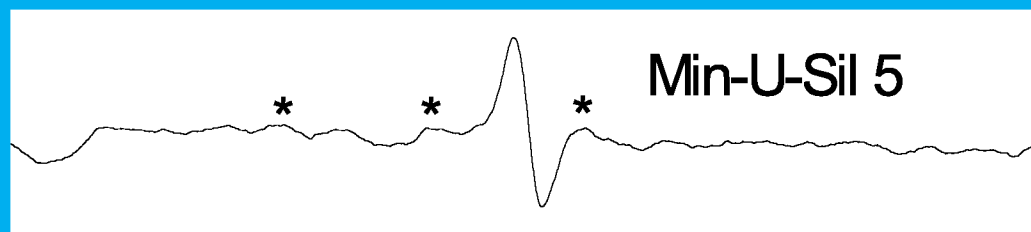
Spin-trapping of Radicals



10 minute grinding



10 minute grinding



30 minute grinding

* : spin-adduct triplet

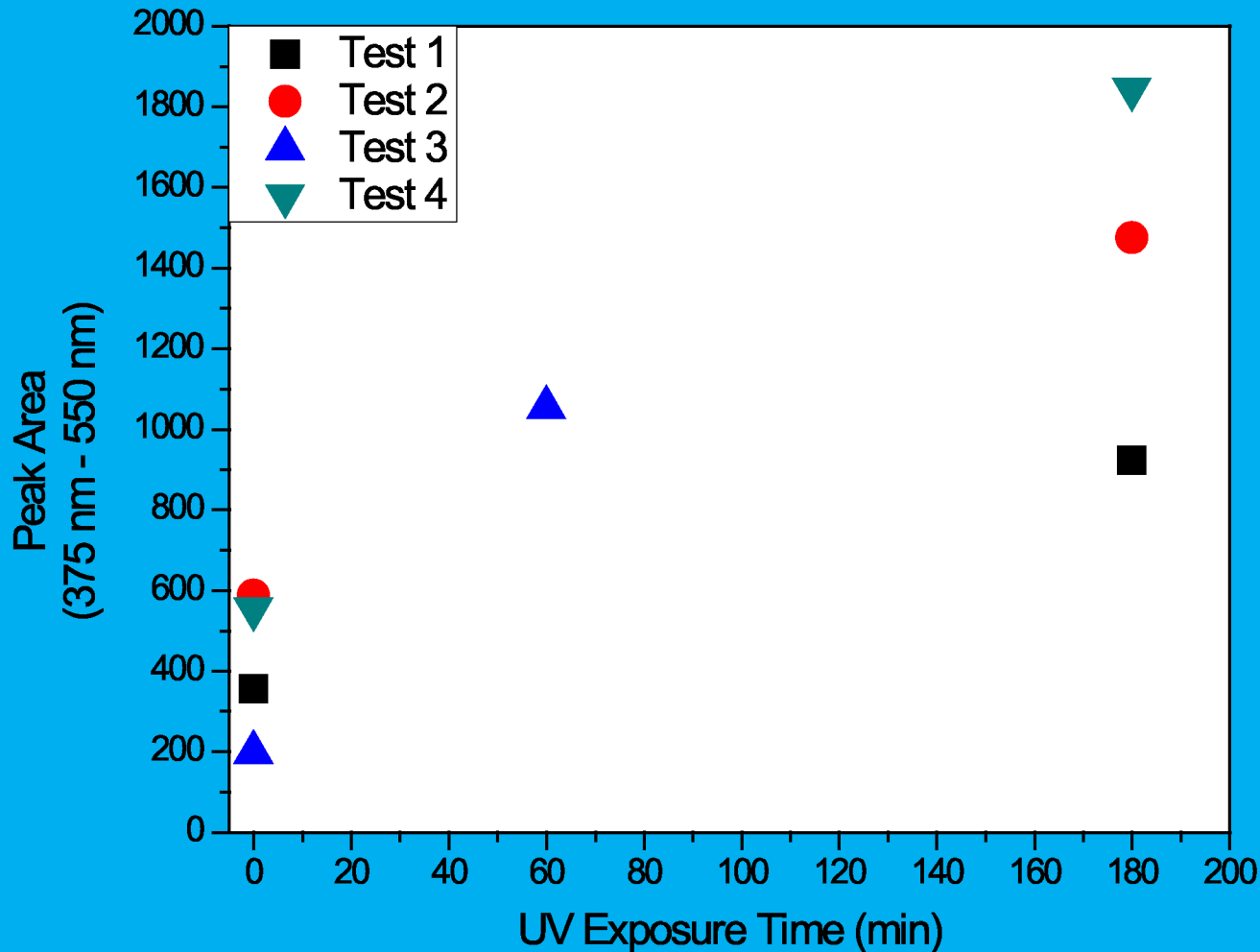
100 mM MNP/acetonitrile

- Activity: quartz < lunar dust simulant < lunar dust
- Activated species + acetonitrile = radicals
 - Radical has no H (no hyperfine coupling peaks)
- Future testing: DMPO in water

A full-page background image showing an astronaut in a white spacesuit standing on the lunar surface. The astronaut is positioned on the left side of the frame, facing right. In the foreground, a large, dark, angular rock formation dominates the center-right. The lunar surface is covered in fine-grained soil and small rocks. In the background, rolling hills and craters are visible under a black sky. A semi-transparent grey rectangular box is centered over the image, containing the text "Activation by UV Exposure" in a bold, orange-to-yellow gradient font.

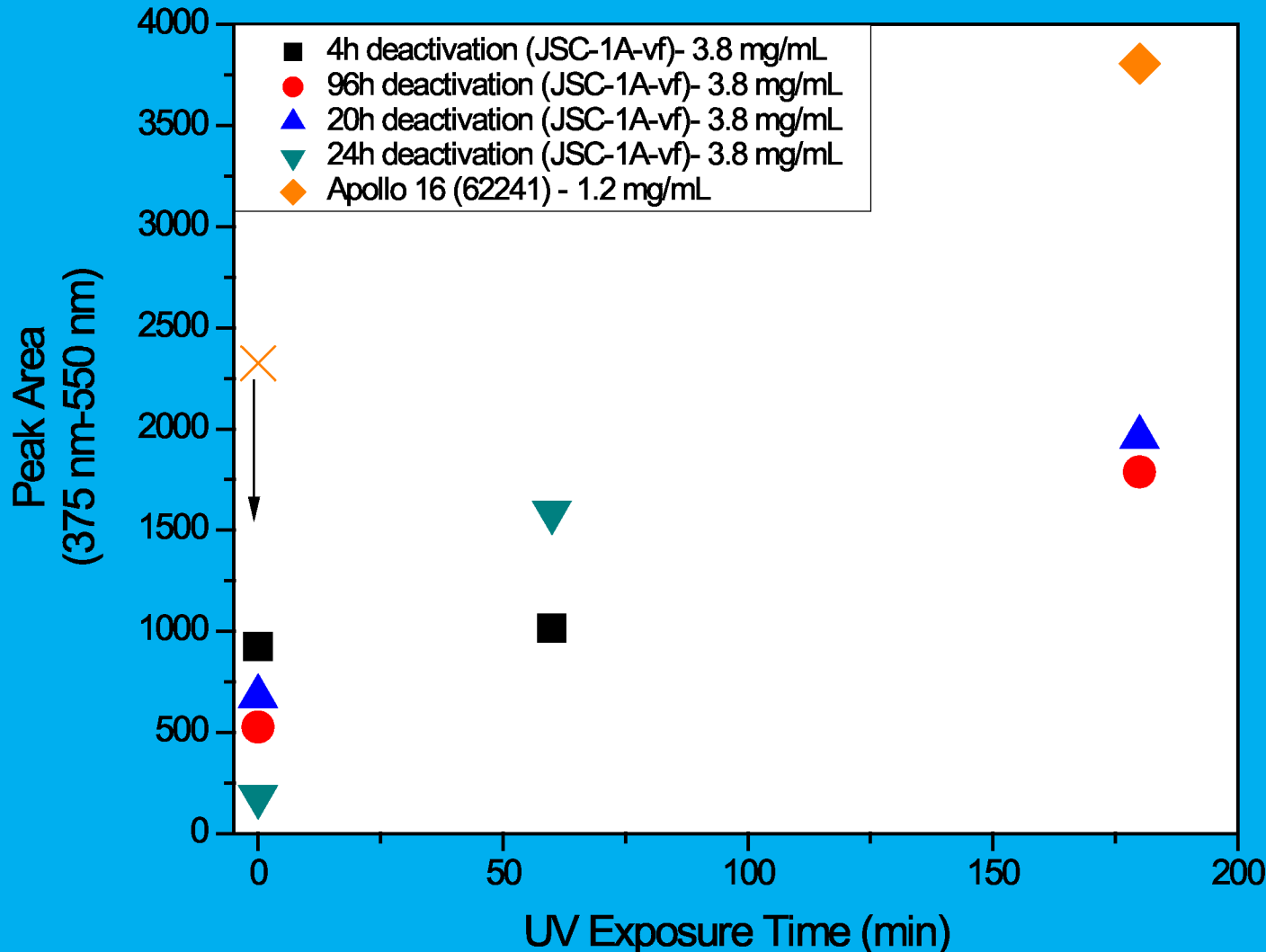
Activation by UV Exposure

UV Activation of Unground Lunar Simulant



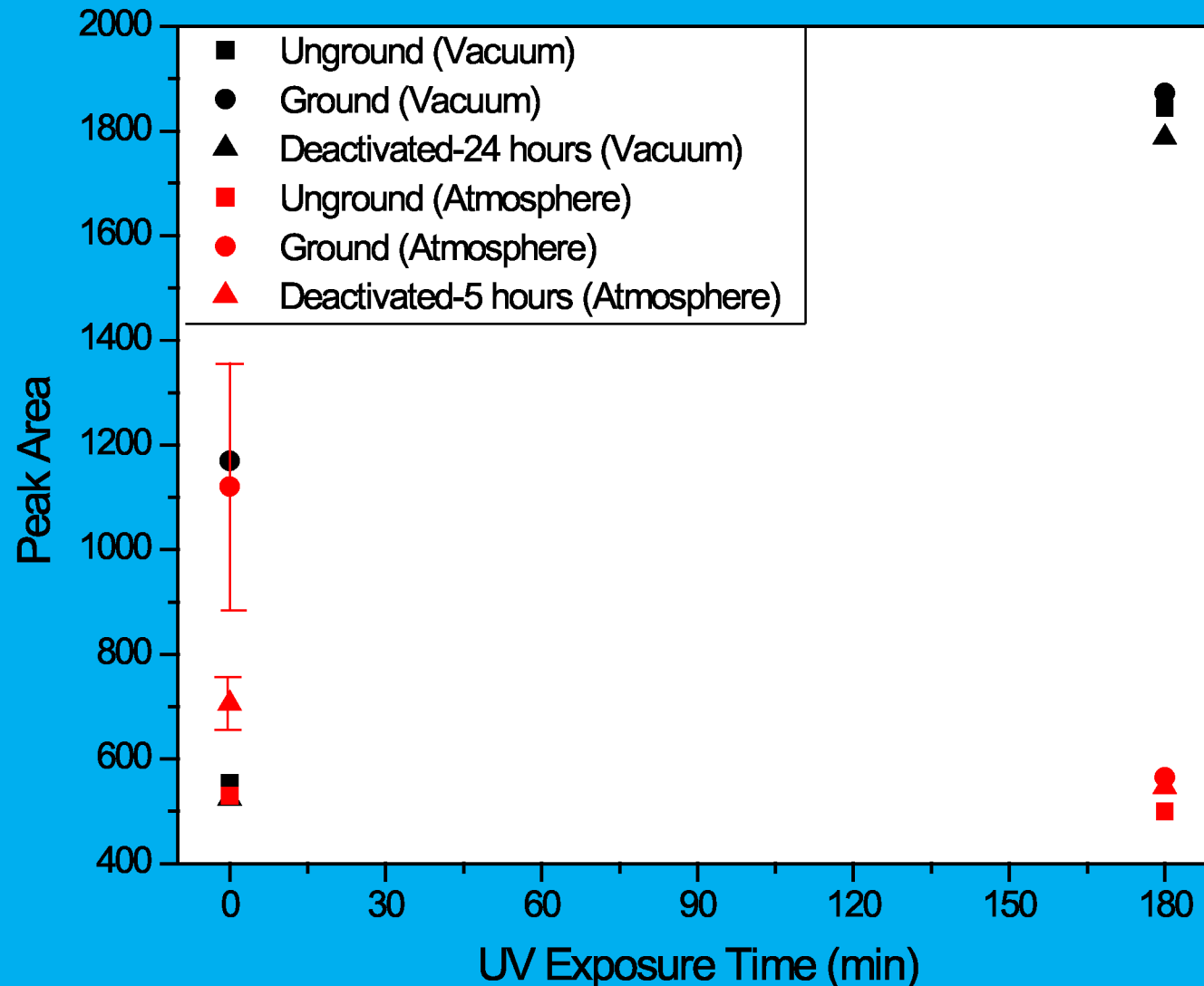
- 3.8 mg/mL JSC-1A-vf
- 10 mM Terephthalate
- 800 W UV
- $\sim 5 \times 10^{-4}$ Torr

UV Reactivation of Ground, Deactivated Lunar Dust and Simulant



Final deactivation point from initial lunar dust testing (> 1 month further deactivation; upper limit for activity)

Effects of Vacuum on UV Activation/Deactivation of Lunar Simulant



• 3.8 mg/mL

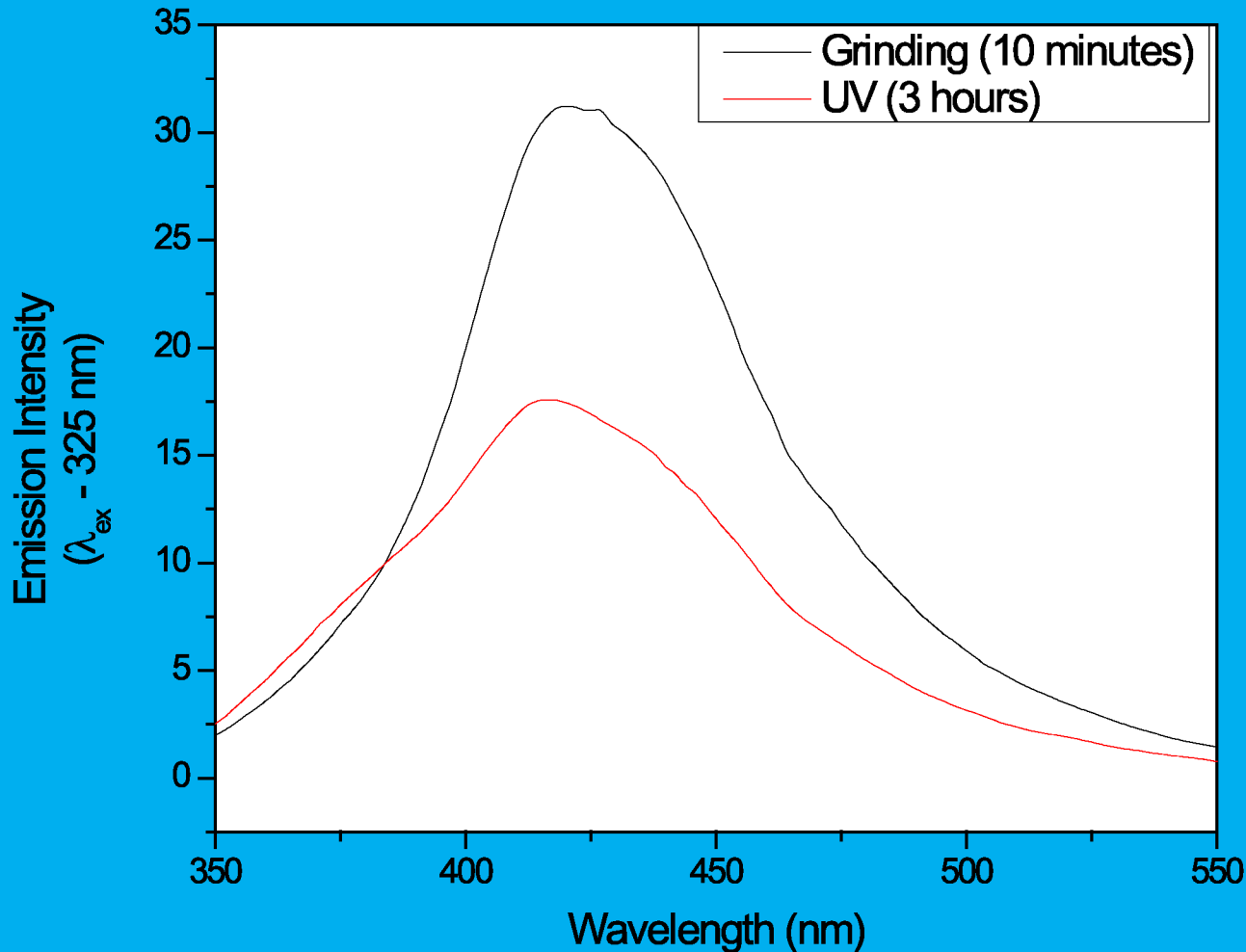
• 10 mM

Terephthalate

• 800 W UV

Exposure of active
simulant to UV in
air leads to
deactivation!

Comparison of Activation by Grinding and UV Exposure



- JSC-1A-vf
- 4 mg/mL
- 800 W UV
- $\sim 5 \times 10^{-4}$ Torr

Summary

- Hydroxyl radical production in solution a measure of reactivity
- Both EPR and fluorescence used
 - Further EPR – 02/10
- Reactivity by grinding: lunar dust > simulant > quartz
- Reactivity: Mare > Highland
- Reactivity correlated with maturity (np-Fe concentration)
- Deactivation tested (50% RH, 25 °C)
 - 50% of initial reactivity ~ 2 hours for lunar dust simulant and ~ 3-4 hours for lunar soils
- UV radiation leads to hydroxyl radical production
 - UV less efficient than grinding

A black and white photograph of the lunar surface, showing a sandy, cratered terrain. A vertical probe or tool is stuck into the ground, and a horizontal tool or rod lies on the surface nearby. The title 'Acknowledgements' is overlaid in white text.

Acknowledgements

- Dr. Yang Liu
- Dan Garrison
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